AD-A165 033 EXAMINING THE AFSC (AIR FORCE SYSTEMS COMMAND) PRODUCTION RATE MODEL(U) COMPTROLLER OF THE AIR FORCE ANDREWS AFB MD DIRECTORATE OF CO.. T D GARDNER 1/1

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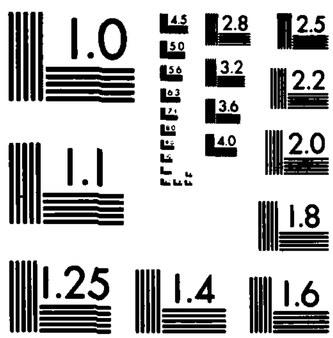

Examining the AFSC Production Rate Model

by

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ABSTRACT

A ~~current~~ problem facing the cost estimator and the program manager is the need to assess program cost impacts resulting from changes in production rate. ~~In responding to this problem,~~ the Air Force Systems Command (AFSC) has developed the Production Rate Model for providing quick same day responses.

The model is based on the assumption that the influence an increasing production rate has on decreasing the unit cost is limited. This idea follows the minimum cost point found on the long run average cost curve in economic theory. In the model's case the point is determined by the manufacturer prior to production. This point is based on plant capacity, capital investment and manpower requirements, anticipated quantities and production rate, and ~~as well as~~ requirements specified by the government.

The AFSC model modifies the learning curve equation by including a variable representing production rate. This equation is used to estimate recurring costs. ~~In addition,~~ there is an internal data base of historical programs containing first unit cost, learning curve slope, and production rate slope generated with a nonlinear regression technique. The nonlinear regression technique was used to reduce the effects of multicollinearity and bias associated with ordinary least squares regression. Virtually all the literature addressing ~~the subject agrees~~ that inserting a variable representing production rate into the basic learning curve equation produces statistically unreliable results. AFSC knows about and accepts the statistical limitation because the model was developed to provide a good approximation of the change in cost that result from a production rate change.

INTRODUCTION

The call usually comes late Friday afternoon, but it is always the same. The Program Element Monitor (PEM) is desperately seeking the impact of a reduction and/or slip in the buy schedule of a major weapon system program. The question, from some congressional panel or Air Force exercise, is put to the Systems Officer (SYSTO) at HQ Air Force System Command (AFSC). It is up to the SYSTO to see that an answer is found. The answer is usually delivered within two days.

HQ AFSC, through its Cost Methods Improvement Program (CMIP), contracted with The Analytical Sciences Corporation (TASC) to develop a model to evaluate the impact of production rate changes on program cost. The model is to provide answers the same day the "what if" exercise is initiated. Some of the ground rules used in developing the model were that the final product be user friendly, use readily available information as inputs, and be free of contractor support after delivery.

BACKGROUND

Techniques for estimating recurring costs, which include the production rate, are receiving more and more attention. AFSC's model uses the basic equation for incorporating production rate (see equation 1). Reviewing some of the literature shows much criticism aimed at the effects of multicollinearity induced by the introduction of the production rate variable. Intuitively, production rate and cumulative quantity appear to be highly related and influence the significance each variable has in predicting unit or lot costs. For this reason a nonlinear approach was used in the AFSC model for estimating model parameters.

This article was written as a means of providing an understanding of the details of the AFSC model in order that it may be better understood as an estimating tool.

The model is formatted into three sections: (1) Data Base Analysis, (2) Analysis of an AFSC Major Program, and (3) new Program Analysis. The Historical Program Data Base is broken into categories which include: fighters, bombers, tactical missiles, tactical armaments, helicopters, and electronics/avionics. Within each category is a listing of weapon system programs. For example:

TABLE 1

FIGHTERS

PROGRAM NAME	LEARNING CURVE	PROD RATE PARAMETER	FIRST UNIT COST ($M)	HIGHEST PROD RATE
F-100	0.930	0.970	6.7	593
F-101	0.920	1.000	7.1	309
F-102	0.740	1.000	20.4	562
F-106	0.950	0.820	14.3	165
F-15 A/B	0.900	1.000	26.4	108
F-15 C/D	0.930	0.750	24.6	97
F-15 E	0.940	0.960	26.6	96
F-16 C/D	0.990	0.990	17.9	180
A-10	0.990	0.890	10.2	144

In deriving the learning curve and production rate parameters in the Historical Data Base, a nonlinear regression technique is used to reduce midpoint bias and multicollinearity. Both will be discussed in more detail later. The value that minimized the sum of the squared error (SSE) was used. The values used may not represent the most logical since a global search of all minimums was not conducted. It is possible that other parameters may exist which are more representative of the program's true parameters.

The Major AFSC Programs section contains 10 of the most current AFSC programs allowing for easier analysis as official program funding profiles are stored here. This means the analyst will not have to retrieve information from the Historical Data Base prior to any analysis. The New Program Analysis section allows analysis of systems not in the Major AFSC Programs section, as well as new developing programs. Once an analysis is completed the analyst can do a rebaseline of the production schedule or a sensitivity analysis. The sensitivity analysis can be done on the first unit cost, learning curve slope, production rate parameter, or optimal production rate. The production schedule and four items in the sensitivity analysis represent the major inputs to the model. In addition, inflation indicies are input by the analyst for Then Year calculations.

EXAMINING THE MODEL

The AFSC model is based on an extension of learning curve theory, using a variable for the production rate parameter as shown in equation 1.

(Equation 1)

$$Y = AX^bR^c$$

where:

Y = cost of unit X
A = cost of the first unit
X = cumulative quantity produced
b = slope of the learning curve
R = production rate in effect (yearly qty)
c = slope of the production rate curve
^ = notation for an exponential function
e.g. x^2 is X squared

The influence an increasing production rate has on decreasing the unit cost is limited [1]. This idea is identical to the long run average cost curve in economic theory. In this case a minimum cost point is determined by the manufacturer prior to production. The point is based on plant capacity, capital investment and manpower requirements, anticipated quantities and production rates, and requirements specified by the government. Therefore, the formulation considers unit cost to be a function of production rate and cost improvement, thus yielding a three dimensional curve such as the one shown in figure 2 [1].

Recurring production costs are estimated by taking the integral of the unit cost equation, equation 1, which produces the following [1]:

(Equation 2)

Zi = (A/B+1)) [((N+Ki + 0.5)^B+1) - ((N+0.5)^B+1)R^C]

This equation is the mathematical basis of the model for estimating all recurring production costs. However, variable A of equation 2 is not the first unit cost -- it is the Surface Initialization Point (SIP). The SIP is calculated internally by the model using the following equation [1]:

(Equation 3)

SIP = FIRST UNIT COST/(TOOLED TO RATE)^c

The SIP rather than the first unit cost is used to initialize the graph shown in figure 2. The SIP represents a theoretical first unit cost if the unit were produced at the tooled to rate. In calculating the SIP the tooled to rate is used because the first lot quantity arbitrarily weights the first lot cost calculation and skews the rest of the estimate.

Once the recurring cost is computed, Engineering Change Order (ECO), nonrecurring, peculiar support, and the program unique costs are added to give a total program cost similiar to that found on an Air Force Form 1537. Figure 1 is a sample output showing the above compilation.

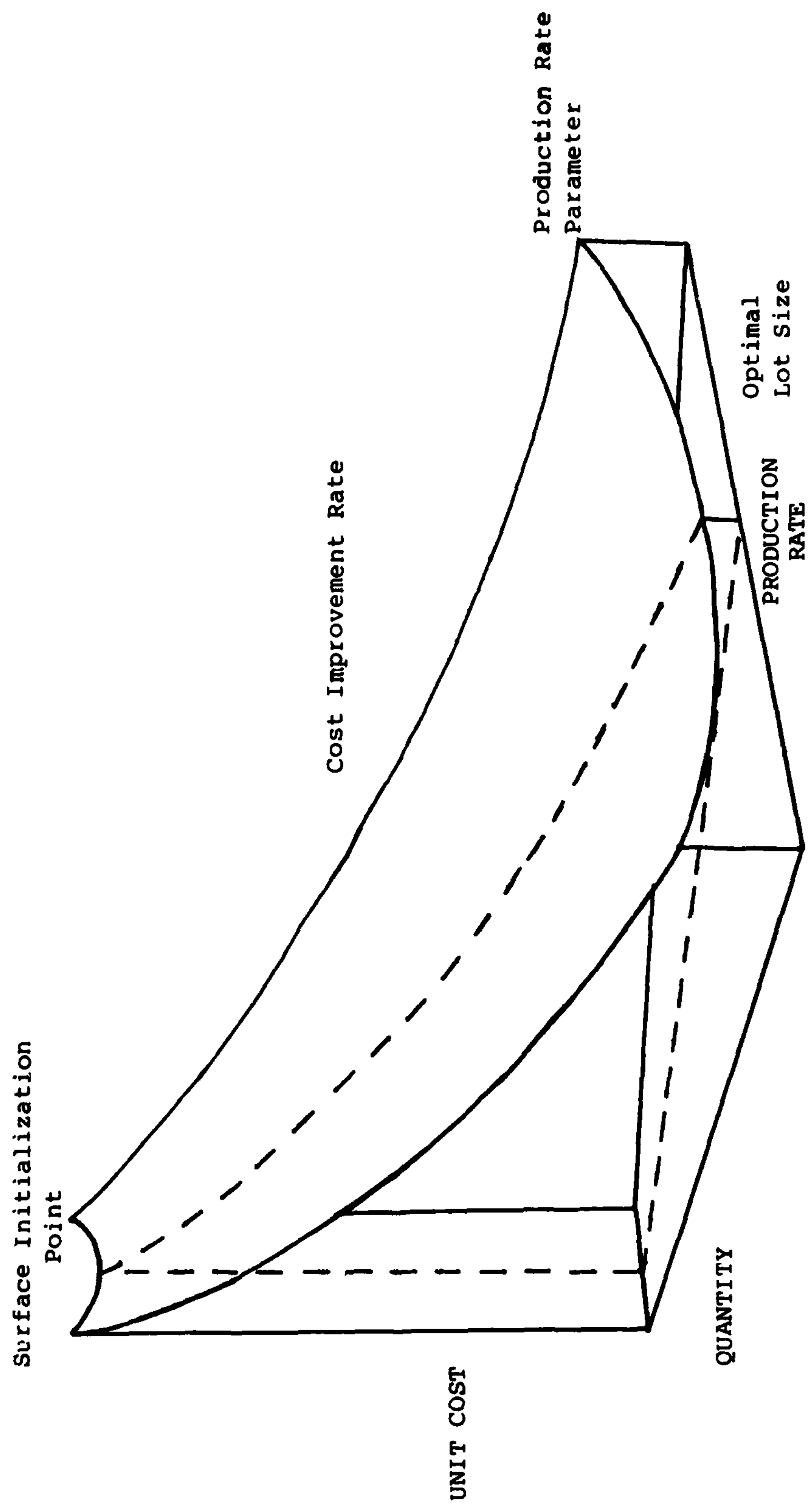
FIGURE 1

COST ELEMENT	FISCAL YEAR						TOTAL
	7X	7X	8X	8X	8X	8X	
QUANTITY	XX	XX	XX	XX	XX	XX	XXX
PME (RECURRING)	XX	XX	XX	XX	XX	XX	XXXX
ECO	X	X	XX	XX	X	X	XX
NONRECURRING	XX	XX	XX	XX	XX	XX	XX
PECULIAR SUPP EQUIP	XX	XX	XX	XX	XX	XX	XXX
PROGRAM UNIQUE	X	X	X	X	X	X	XX
TOTAL BASE YEAR	XX	XX	XX	XX	XX	XX	XXXX
INFLATION INDEX	X	XX	X	X	XX	XX	
TOTAL THEN YEAR	XX	XX	XX	XX	XX	XX	XXXX

HISTORICAL DATA BASE

In deriving the Historical Data Base, a nonlinear regression was used to find the first unit cost, learning curve and production rate slopes. As stated earlier, the nonlinear technique was used to reduce midpoint bias and multicollinearity. However, the issue of dependence between production rate and cum quantity is not specifically addressed. Previous studies are cited as a basis for the nonlinear approach. First, bias is introduced with the selection of the lot midpoints -- averages which are used in the log linear, Ordinary Least Squares (OLS) equation used to estimate the cost improvement parameters. A Rand study states the OLS approach leads to biased estimates of the cost improvement parameters because the lot midpoint is a function of the improvement curve [7]. Further support is found in a study by Goldberger, indicating that logarithmic transformation biases the estimation of the first unit cost [4]. Documentation for the model does not show the extent of reduction the nonlinear approach has on the problem of multicollinearity. As such, a true evaluation of the developer's claim was not conducted, although their approach has an intuitive appeal.

FIGURE 2


Production Rate
Parameter
Optimal
Lot Size
Cost Improvement Rate
PRODUCTION
RATE
Surface Initialization
Point
QUANTITY
UNIT COST

If true independence is to be achieved when using the linear OLS described above, then the covariance of the variables must be equal to zero. When the production rate equation, equation (1), is transformed and the least squares estimator for c (the production rate slope) is found, the results show that the covariance is not equal to zero. The result is equal to the summation of X' plus the summation of R'; $\sum X' + \sum R'$ [2]:

(Equation 1)

$$Y = AX\hat{}bR\hat{}c$$

transformed:

(Equation 4)

$$\ln Y = A + b(\ln X) + c(\ln R) + e$$

where:

lnY = logarithm of the unit cost of X
lnR = logarithm of the production rate
lnX = logarithm of the estimated lot midpoint defined as the true lot midpoint plus some error, β
e = random error
A,b,c are to be estimated

Equation (4) can now be rewritten as follows:

(Equation 5)

$$\ln Y = A + b(2n(X + \beta)) + C(\ln R) + e$$

Solving for the least squares estimator for c results in:

$$c = \frac{\sum Y'R' \sum X'\hat{}2 - \sum Y'X' \sum X'R'}{\sum X'\hat{}2 \sum Y'\hat{}2 - (\sum X'Y')\hat{}2}$$

where:

$$Y' = \ln Y - \overline{\ln Y}$$
$$X' = \ln(X + \beta) - \overline{\ln(X + \beta)}$$
$$R' = \ln R - \overline{\ln R}$$

From the least squares estimator of c comes the covariance $\sum X' + \sum R'$ identified earlier which is not equal to zero. This indicates that true independence does not exist for the production rate equation when regressed in linear form and why the nonlinear approach was used.

Further compounding the problem were the results of a recent study by Sherbrooke and Associates of the AIM-7F (Sparrow missile) showing, through linear regression, a non-significant production rate parameter [8]. Examining the results of the study and looking at the difference between the log of the production rate and the estimated lot midpoints a covariance of 0.84 is found. This indicates that one variable may assume all explanatory significance of the other when the two variables are highly correlated. In other words, the true significance of the other variable can not be evaluated [2].

Because of this additional problem a nonlinear, weighted least squares method developed by Newton was used. This method is equivalent to the Gauss-Newton method contained in the Statistical Analysis System (SAS) computer package [1]. Using the nonlinear regression, equation (1) was solved for the learning curve slope (b), production rate slope (c), and first unit cost. In doing so, the regression produced a learning curve slope which is affected by the production rate and its slope.

Evaluating the production rate slope is more difficult as its value is calculated and has little historical data to support the values. This slope indicates to what degree costs would change as the production rate changes. This is certainly germane to recurring costs; however, the bottom line cost will be determined by the allocation of the overhead costs. Building a relationship between production rate and overhead costs for estimating purposes is difficult to quantify. The relationship would be related to the company's overall industrial base and production rate at any one point in time. Developing this relationship was not within the scope of effort for developing the AFSC model. Follow-on efforts will encompass this complex relationship.

To update the Historical Data Base, the analyst must use a nonlinear program outside the model to determine the values for the first unit cost, learning curve and production rate slopes. In addition, if the analyst wants to use any of the historical learning curve or production rate slopes in the New Program Analysis segment, the model only provides simple averages. More analytical rigor could have been provided by using a regression of the historical data or a weighted average calculation. This will be discussed in the New Program Analysis review.

MAJOR AFSC PROGRAMS

This segment of the model contains the current program funding profile for major AFSC systems. This section of the model includes the following programs:

1. F-15C/D/E
2. B-1B
3. KC-10
4. F-16
5. HH-60D
6. JTIDS (CLASS II)
7. LANTIRN
8. IIR MAVERICK
9. HARM
10. T-46A

The data for these systems will be updated periodically to include the most current official program information.

This segment of the model allows for easier analysis as the analyst will not have to dig through the Historical Data Base to retrieve learning curve, production rate, or first unit cost information. The current production schedule is also stored here, and program cost information is presented in base year dollars. The analyst need only input changes to the program information in order to conduct any analysis. Once the changes are input, the recurring costs are calculated using equation (2).

NEW PROGRAM ANALYSIS

In this segment of the model the analyst conducts analysis of new programs not found in the Major AFSC Program segment. This segment of the model requires the most input from the analyst. The analyst must determine what learning curve and production rate slope values are needed. This can be done in two ways. The first is from previous contractor experience; the second is from the Historical Data Base. If the second alternative is used, the analyst must select the historical systems which best represent the system being analyzed. The model takes the information for the systems selected from the Historical Data Base (reference Table 1) and computes a simple average for the learning curve and production rate slopes respectively. For example, a new generation ground attack aircraft is being considered. The analyst determines that the F-15E, F-16E, and A-10 best represent some of the characteristics of the new system. Based on the analyst's selection, the model computes an average from the historical learning curve and production rate slopes. The new averages are the values used as inputs for the New Program Analysis.

For this example, the simple average calculated for the production rate parameter is affected by a low value for the F-16E production rate slope. In arriving at the new values, the analyst must take into consideration what characteristic(s) to focus on when selecting programs from the Historical Data Base. This is important as it may help explain results that don't follow "normal" behavior. In this instance the F-16E production rate slope may be lower than expected because of the modernized plant facility. This may cause results to be different than expected. Regardless of what the analyst focuses on as the driving characteristic, a simple average calculation does not appropriately weight a system such as the F-16. To follow the analytical rigor used to develop the historical data base, a weighted average or regression calculation could be used.

After determining the learning curve and production rate slopes, the analyst must input the remaining data elements. These are determined outside of the model and include first unit cost, starting year of production, yearly production schedule, program base year, and inflation indicies (for Then Year calculations). Recurring costs are again calculated using equation (2). Once the output is presented, the analyst can then perform a rebaseline or sensivity analysis.

OUTPUT REPORTS

Output reports are provided for the Major AFSC Program and New Program Analysis segments of the model. Once a system is selected from the Major AFSC Program data base, a multiple page (video display screen) report is provided as shown by the example in figure 3. The information provided in this report is the most current program funding profile.

FIGURE 3

MAJOR PROGRAM DATA BASE   PAGE 1 OF 3

System:	F-15C/D/E	Prime contractor:	McDonnell Douglas
Type:	Fighter	Primary Facility:	St. Louis MO

FIRST UNIT COST	55.024 MILLION
COST IMPROVEMENT RATE:	0.903
PRODUCTION RATE PARAMETER:	0.906
TOOLED RATE:	144
INITIAL PRODUCTION YEAR:	1984
PROGRAM BASE YEAR:	1983

FIGURE 3 (cont.)

PRODUCTION SCHEDULE (COSTS IN MILLIONS)

	FY84	FY85	FY86	FY87	FY88
QUANTITY	36	48	60	72	96
PME	906.4	1151.1	1380.8	1362.1	1354.8
ECO	15.4	19.3	23.0	22.8	22.6
NON-RECURRING	104.3	52.6	22.6	8.9	4.3
PEC SUPP EQP	395.5	384.7	390.4	343.5	297.8
PROG UNIQUE	144.9	154.5	130.4	124.1	117.2
TOTAL BASE YEAR					
INFLATION INDEX					
TOTAL THEN YEAR					

If a rebaseline of the program is done a similiar report is provided. The difference being that the program and contractor specific information is not included, as can be seen in figure 4 below. The Base Year and Then Year deltas show the change from the original to the rebaseline. The last page of the rebaseline report is a sample POM submission based on the new schedule (see figure 5). Included in all of the reports are TY costs, based on the indicies provided by the analyst.

FIGURE 4

30 NOV 84 13:50:45 REBASELINE REPORT (Costs in $M) PAGE 1 OF 3

SYTEM: KC-10 Tooled Rate: 10
TYPE: Transport Program Base Year: 1976

Fiscal Year	1978	1979	1980	1981	1982
Lot size	2	4	6	4	8
Inflation indicies	1.335	1.455	1.586	1.727	1.820
Recurring	97.1	151.4	220.7	146.1	286.5
ECO	7.0	6.1	5.3	6.1	4.4
Nonrecurring	0.0	47.7	0.0	0.0	0.0
Peculiar Support	0.0	3.6	6.8	11.5	151.7
Program Unique	-19.2	-39.2	-60.0	-40.0	-56.0
Base-year Total	66.8	169.6	172.8	123.8	386.6
Then-year Total	89.2	246.7	274.0	213.8	703.6
Base-year Delta	N/A	51.4	47.7	-53.7	122.6
Then-year Delta	N/A	74.8	75.7	-92.8	223.2

FIGURE 5

REBASELINE REPORT (Costs in $M) PAGE 3 OF 3

SYSTEM: KC-10 Tooled Rate: 10
TYPE: Transport Program base year: 1976

POM SUBMISSIONS

	FY85 and prior	FY86	FY87	FY88	FY89	FY90	To Complete
BASE YEAR	919.6	N/A	N/A	N/A	N/A	N/A	N/A
THEN YEAR	1,527.4	N/A	N/A	N/A	N/A	N/A	N/A

When doing a sensitivity analysis the model will prompt for an upper and lower bound, and increment of increase. The output provides costs for each increment between the bounds at a summary and per increment level. The increment level detail is given by year showing the change from the comparison value as an absolute and percent amount (see figures 6 and 7).

FIGURE 6

PARAMETER SENSITIVITY REPORT PAGE 1 OF 4

SYSTEM: KC-10 Sensitivity parameter: FIRST UNIT COST
TYPE: Transport Comparison value: 38.87
SCHEDULE: Rebaselined Value range from 35 to 55 by 10

PARAMETER VALUE	TOTAL PME ($M) Base	Then	DELTA PME ($M) Base	Then	PCT CHANGE Base	Then
35.	793.7	1,301.9	-90.1	-147.8	-10.2	-10.2
45.	1,020.5	1,673.8	136.7	224.2	15.5	15.5
55.	1,247.2	2,045.8	363.4	596.1	41.1	41.1

FIGURE 7

PARAMETER SENSITIVITY REPORT PAGE 2 OF 4

SYSTEM: KC-10 Sensitivity parameter: FIRST UNIT COST
TYPE: Transport Comparison value: 38.87
SCHEDULE: Rebaselined Value range from 35 to 55 by 10

PARAMETER VALUE: 35. (Cost units are millions of dollars.)

		FY78	FY79	FY80	FY81	FY82
BASE YEAR:	Costs:	71.0	135.9	198.2	131.2	257.3
	Changes:	-8.1	-15.4	-22.5	-14.9	-29.2
	Percent:	-10.19	-10.19	-10.19	-10.19	-10.19
THEN YEAR:	Costs:	94.8	197.8	314.4	226.7	468.3
	Changes:	-10.8	-22.5	-35.7	-25.7	-53.2
	Percent:	-10.19	-10.19	-10.19	-10.19	-10.19

VALIDATION OF THE MODEL

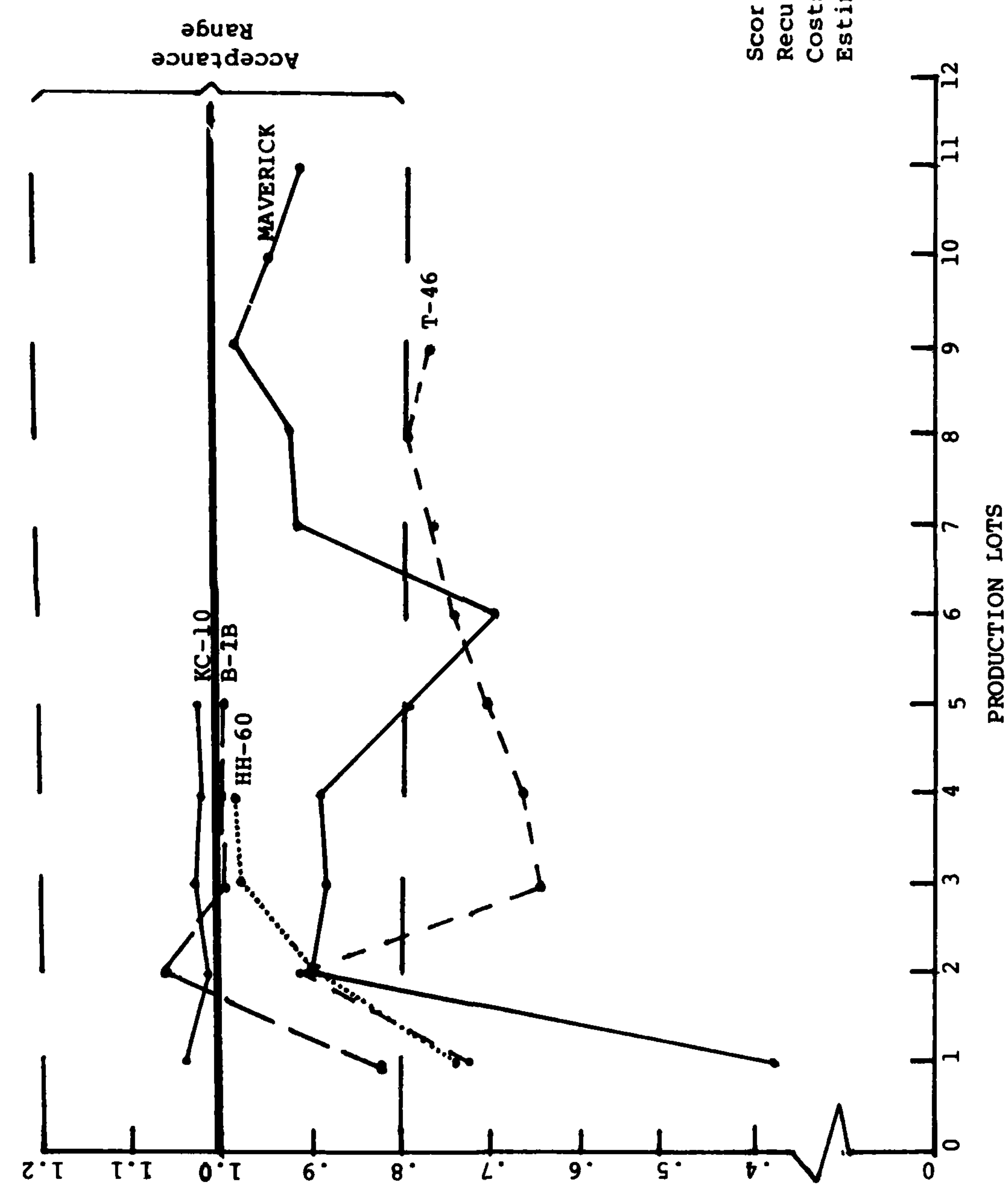
Before the model is distributed to the field for implementation, validation of the model's output will be conducted by HQ AFSC. The process for validation has started and uses a concept similiar to one identified by Graver [5]. This technique "scores" the results of the model.

The technique for scoring will be done using the model's current data base and the official Air Force Fiscal Year 87 Program Objective Memorandum (POM). Using the current data base, cost estimates for the quantities in the 87 POM will be made and compared to the dollar amounts in the POM. Then the estimate will be divided by the POM amount to develop a score. Obviously the closer the ratio is to one the better the score. The results of the scoring exercise are provided in figure 8. An acceptance band between .80 and 1.20 was chosen as a good score. If the model scores are consistently within the acceptance band the output of the model will not require extensive calibration. If the results are eratic an explanation is required. For example, the IIR Maverick graph in figure 8 shows a dip in its score from FY 85, .89, to FY 86, .67. The reason for the dip is a change in quantity from the model's data base to the 87 POM. Although the quantity was reduced by 6,000 missiles, the dollars associated with the quantity were not reduced by a proportionate amount. If you adjust the model results by the increase in the unit cost the score becomes .84 not .67.

If the extreme variances in the model's output can be explained then AFSC can use and understand the model on a routine basis. The above scoring example, as all scores, was based on comparing recurring costs only. This was done because of the wide range between the model's data base and the 87 POM for the other costs.

One "what if" exercise was conducted earlier this year with Aeronautical Systems Division's (ASD) director of Cost Analysis for quantity changes to the F-15 program. The exercise done by the Program Office showed a decrease in unit cost from 5 to 10 percent. When the same changes were calculated using the Rate Model, a change in unit cost from 4 to 8 percent was experienced. The results were encouraging but further validation is needed.

FIGURE 8



Scoring Recurring Costs Estimate : 87 Summer Review

SUMMARY

Some of the theoretical ideas behind the model may still be questioned; however, these problems plague the basic equation used to incorporate production rate. The model does appear, based on the validation process, to provide a good estimate of recurring cost for "what if" exercises. In addition the model provides a good foundation for future expansion.

AFSC has already started a study to incorporate effects of changes in the production rate on overhead. This complex relationship is a key to determining the final program cost. Some studies such as Gulledge's [6] are a good attempt to capture factors other than cumulative quantity and production rate effecting cost. Additionally, AFSC has sponsored a thesis undertaken by Bolton [3] at the Air Force Institute of Technology. This effort is to examine the reduction in multicollinearity as a result of estimating parameters with the nonlinear approach. In addition, new equations will be examined to see if the dependency between the variable can be eliminated and true independence found. This effort should be completed by September 1985.

Areas for future consideration include the addition of a nonlinear program to update the data base. A more rigorous approach for developing learning curve and production rate slopes used in the New Program Analysis may be developed to replace the simple average calculation. An exploration of all minimum values resulting from the nonlinear regression should be undertaken to find the most logical value. Lastly, the treatment of contractor overhead must be developed from the parametric standpoint. The efforts are some of the areas of future expansion allowed by the model.

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